

CLAIMS

What is claimed is:

1. A semiconductor device having a composite dielectric layer, comprising:
 - a semiconductor substrate;
 - alternating sub-layers comprising a first dielectric material and a second dielectric material on the semiconductor substrate, the sub-layers forming a composite dielectric layer having at least two sub-layers of at least one of the first dielectric material and the second dielectric material,
 - wherein one of the first dielectric material and the second dielectric material is a high-K dielectric material and an other of the first dielectric material and the second dielectric material is a standard-K dielectric material comprising aluminum oxide; and
 - the composite dielectric layer comprises a reaction product of the high-K dielectric material and the standard-K dielectric material.
2. The semiconductor device of claim 1, wherein the standard-K dielectric material further comprises at least one of silicon dioxide, silicon oxynitride, silicon nitride, and silicon-rich silicon nitride.
3. The semiconductor device of claim 1, wherein the high-K dielectric material comprises at least one of hafnium oxide (HfO_2), zirconium oxide (ZrO_2), tantalum oxide (Ta_2O_5), barium titanate (BaTiO_3), titanium dioxide (TiO_2), cerium oxide (CeO_2), lanthanum oxide (La_2O_3), lanthanum aluminum oxide (LaAlO_3), lead titanate (PbTiO_3), strontium titanate (SrTiO_3), lead zirconate (PbZrO_3), tungsten oxide (WO_3), yttrium oxide (Y_2O_3), bismuth silicon oxide ($\text{Bi}_4\text{Si}_2\text{O}_{12}$), barium strontium titanate (BST) ($\text{Ba}_{1-x}\text{Sr}_x\text{TiO}_3$), PMN ($\text{PbMg}_x\text{Nb}_{1-x}\text{O}_3$), PZT ($\text{PbZr}_x\text{Ti}_{1-x}\text{O}_3$), PZN ($\text{PbZn}_x\text{Nb}_{1-x}\text{O}_3$), and PST ($\text{PbSc}_x\text{Ta}_{1-x}\text{O}_3$).
4. The semiconductor device of claim 1, wherein the reaction product comprises a high-K derived metal atom, an aluminum atom and an oxygen atom.

5. The semiconductor device of claim 1, wherein the first dielectric material is the high-K dielectric material.
6. The semiconductor device of claim 1, wherein the second dielectric material is the high-K dielectric material.
7. The semiconductor device of claim 1, wherein the composite dielectric layer comprises at least a portion of the sub-layers of the first dielectric material and the second dielectric material, separated by a sub-layer of a reaction product of the first dielectric material and the second dielectric material.
8. The semiconductor device of claim 1, wherein the composite dielectric layer comprises a substantially uniform layer of the reaction product of the first dielectric material and the second dielectric material.
9. The semiconductor device of claim 1, wherein the composite dielectric layer comprises from 3 to about 10 sub-layers of the first dielectric material and the second dielectric material.
10. The semiconductor device of claim 9, wherein each pair of sub-layers of the first dielectric material and the second dielectric material are separated by a reaction product sub-layer.
11. The semiconductor device of claim 1, wherein the composite dielectric layer is a gate dielectric layer in the semiconductor device.
12. The semiconductor device of claim 1, wherein the composite dielectric layer is a gate dielectric layer formed on the semiconductor substrate.

13. A semiconductor device having a composite dielectric layer, comprising:
 - a semiconductor substrate;
 - a composite gate dielectric layer on the semiconductor substrate, the composite gate dielectric layer comprising a reaction product of a first dielectric material and a second dielectric material,
 - wherein one of the first dielectric material and the second dielectric material is a high-K dielectric material and another of the first dielectric material and the second dielectric material is a standard-K dielectric material comprising aluminum oxide; and
 - the reaction product comprises a metal aluminate wherein the metal is a high-K derived metal.
14. The semiconductor device of claim 13, wherein the standard-K dielectric material further comprises at least one of silicon dioxide, silicon oxynitride, silicon nitride, and silicon-rich silicon nitride.
15. The semiconductor device of claim 13, wherein the high-K dielectric material comprises at least one of hafnium oxide (HfO_2), zirconium oxide (ZrO_2), tantalum oxide (Ta_2O_5), barium titanate (BaTiO_3), titanium dioxide (TiO_2), cerium oxide (CeO_2), lanthanum oxide (La_2O_3), lanthanum aluminum oxide (LaAlO_3), lead titanate (PbTiO_3), strontium titanate (SrTiO_3), lead zirconate (PbZrO_3), tungsten oxide (WO_3), yttrium oxide (Y_2O_3), bismuth silicon oxide ($\text{Bi}_4\text{Si}_2\text{O}_{12}$), barium strontium titanate (BST) ($\text{Ba}_{1-x}\text{Sr}_x\text{TiO}_3$), PMN ($\text{PbMg}_x\text{Nb}_{1-x}\text{O}_3$), PZT ($\text{PbZr}_x\text{Ti}_{1-x}\text{O}_3$), PZN ($\text{PbZn}_x\text{Nb}_{1-x}\text{O}_3$), and PST ($\text{PbSc}_x\text{Ta}_{1-x}\text{O}_3$).
16. A semiconductor device having a composite dielectric layer, comprising:
 - a semiconductor substrate;
 - alternating sub-layers comprising a first dielectric material and a second dielectric material on the semiconductor substrate, the sub-layers forming a composite dielectric layer having from 3 to about 10 sub-layers of the first dielectric material and the second dielectric material, each pair of sub-layers separated by a sub-layer of a

reaction product of the high-K dielectric material and the standard-K dielectric material,

wherein one of the first dielectric material and the second dielectric material is a high-K dielectric material and another of the first dielectric material and the second dielectric material is a standard-K dielectric material comprising aluminum oxide.

17. The semiconductor device of claim 16, wherein the standard-K dielectric material further comprises at least one of silicon dioxide, silicon oxynitride, silicon nitride, and silicon-rich silicon nitride.

18. The semiconductor device of claim 16, wherein the high-K dielectric material comprises at least one of hafnium oxide (HfO_2), zirconium oxide (ZrO_2), tantalum oxide (Ta_2O_5), barium titanate (BaTiO_3), titanium dioxide (TiO_2), cerium oxide (CeO_2), lanthanum oxide (La_2O_3), lanthanum aluminum oxide (LaAlO_3), lead titanate (PbTiO_3), strontium titanate (SrTiO_3), lead zirconate (PbZrO_3), tungsten oxide (WO_3), yttrium oxide (Y_2O_3), bismuth silicon oxide ($\text{Bi}_4\text{Si}_2\text{O}_{12}$), barium strontium titanate (BST) ($\text{Ba}_{1-x}\text{Sr}_x\text{TiO}_3$), PMN ($\text{PbMg}_x\text{Nb}_{1-x}\text{O}_3$), PZT ($\text{PbZr}_x\text{Ti}_{1-x}\text{O}_3$), PZN ($\text{PbZn}_x\text{Nb}_{1-x}\text{O}_3$), and PST ($\text{PbSc}_x\text{Ta}_{1-x}\text{O}_3$).

19. The semiconductor device of claim 16, wherein the composite dielectric layer is a gate dielectric layer in the semiconductor device.

20. The semiconductor device of claim 16, wherein the composite dielectric layer is a gate dielectric layer formed on the semiconductor substrate.